Circular No. 6072
June, 1928.

INFORMATION CIRCULAR

DEPARTMENT OF COMMERCE - BUREAU OF MINES

RUSSIAN PAPERS ON MEASUREMENTS OF TERRESTRIAL RADIOACTIVITY[1]

By L. N. Bogoiavlensky, A. A. Lomakin, and A. Cherepenikov

WITH A SUPPLEMENTARY CHAPTER ON RADIOACTIVE SUBSTANCES AND METHODS FOR LOCATING THEM

By F. W. Lee

EXPERIMENTS ON HIGHLY PENETRATING RADIATIONS FROM THE EARTH

By L. N. Bogoiavlensky and A. A. Lomakin[2]

The measurements of penetrating radiations from the earth at various places are neither numerous nor systematic. Simultaneous observations were made with various apparatus by St. Meyer and Schweidler and reported in Radioactivitat for 1916, page 475. In these experiments the geology of the region was not taken into consideration at the place where the tests were made. Nevertheless, Wulf has shown some connection between penetrating radiations and the geology of the place where his experiments were performed; he found a difference in the indications of the electrometer upon carrying this instrument from place to place. At the same time it may be considered a well-ascertained fact that the degree of concentration of radioactive elements in the earth has an enormous influence on the penetrating radiations. Measurements above the ocean and measurements of the ocean water have shown that the water contains very little radium and radioactive substance. Radioactivity also gives a minimum value for the intensity of the penetrating radiations. The experiments described below indicate that the intensity of penetrating radiations near the surface of the earth changes sharply, in quality and quantity, even within a few meters.

In the past five years a systematic investigation has been made of the penetrating radiations from the earth, in which a special method developed by the authors was used.

---

1 - This article is not subject to copyright. Reprinting, with customary acknowledgment to the Bureau of Mines, will be welcomed.

2 - Translated from the Russian by A. Seletzky.

Digitized by Google

Method of Radiometric Contouring

The method of radiometric contouring consists in measuring the intensity of radiation at definite points on the earth's surface. These points are plotted directly upon the map of the region, and by using the data obtained by the measurements and interpolating between values of the above map it is possible to draw curves of equal intensity representing the distribution of radioactivity. With the aid of filters it is possible to determine the character of the earth's radiation -- that is, the degree of hardness -- and it is also possible to represent these variations upon a map by curves.

Apparatus

The apparatus for this experiment was a portable electrometer of special construction. The body of the apparatus rotates about its vertical axis, and the angle of rotation may be measured on a scale. The brass wall of the chamber is 3 mm. thick, and it is covered on all sides by lead hoods, each 10 mm. thick. In order to study the vertical radiations from the ground there is provided a lower window with an area of 18 per cent of the total surface of the apparatus. This window is round and may be closed by as many as six lead filters, each $2\frac{1}{2}$ mm. thick. The side window is rectangular and has an area of about 23 per cent of the surface of the apparatus. This window may be closed with screens of the same thickness as the materials of the walls. However, in these experiments this window was not used. In the center of the chamber is an electroscope composed of a rod with a gold leaf. The defects of amber insulation were eliminated by a method devised by Wilson. A battery of normal elements capable of a potential of 200 volts, placed in the cylinder on the lid of the apparatus, served to charge the electroscope. The volume of the air in the chamber is 1,650 cm.^{3} The electrostatic capacity of the system is 0.725 cm., and the voltage sensitivity allowed one scale division for 0.65 volt.

Locality of Observations

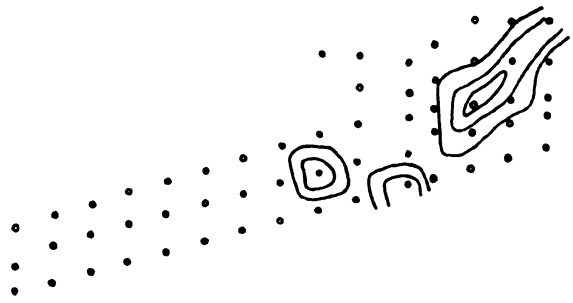
The experiments were made at Pyatygorsk in the Caucasus, a region where radium is deposited in travertines and breccia. The deposits settled out of waters flowing along crevices from northeast to southwest. The peculiarity of these deposits of radium having had their source in colloidal solution is evidenced by the presence of iron and manganese and by the absence of uranium. The radium contents of the deposits at several places near the surface attained a value as great as 5×10^{-10} gr. per gram. The experiments were made at the foot of a hill 50 to 60 meters high, consisting of travertines. Control experiments were also performed in and near Leningrad.

Results of Radiometric Contouring

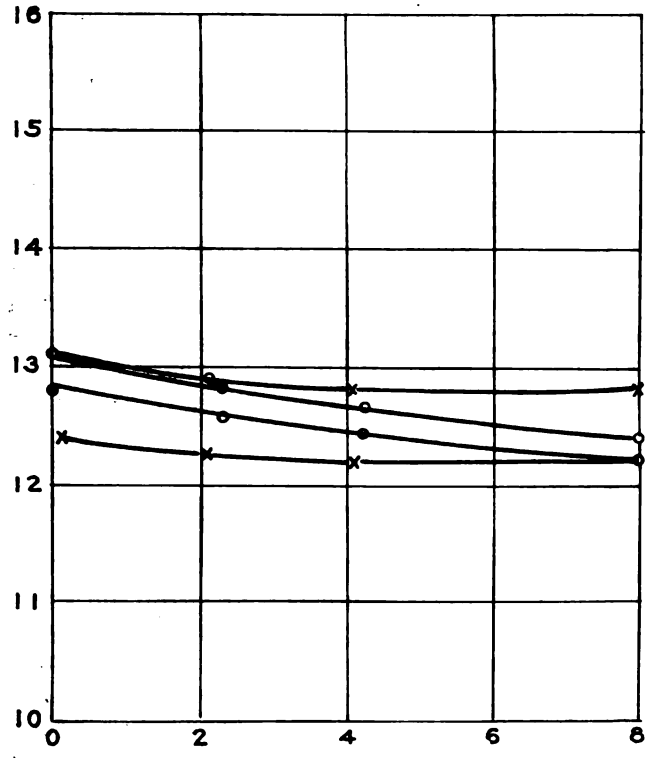
In a region of 10,500 square meters, 92 points were selected 6 to 12 meters from each other. At these points measurements of intensity were made with two and four lead filters 5 and 10 mm. in thickness; at other points experiments were made with 2, 4, and 6 filters. In all these experiments the side window was closed.

Digitized by Google

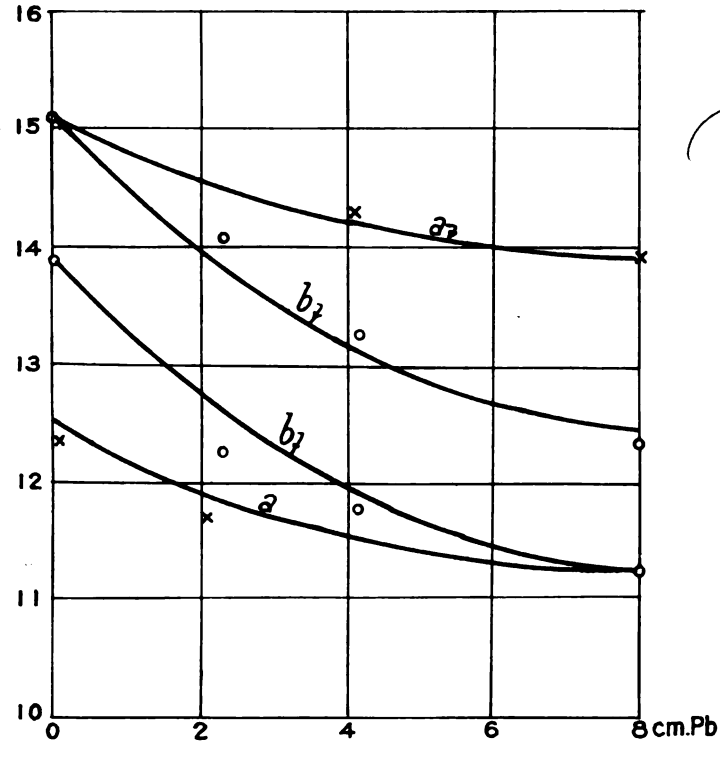
A



B



C



D

Figure 1

Digitized by Google

The radiometric contour lines shown in Figure 1, A and B, have a general direction from northeast to southwest, corresponding to the direction of the crevices of the earth. On the first map (fig. 1, A) are shown curves of equal intensity observed with a lead filter 5 mm. in thickness. The values of intensity fluctuated from 11 to 23.7 ions. On the second map (fig. 1, B) the curves show the same general degree of hardness with a lead filter 10 mm. in thickness. The relation between the 5-mm. and the 10.mm. thicknesses is shown in the region by comparison of A and B, Figure 1. The ratio of intensity between these two figures varied from 1 to 1.36. It is noticed that the curves in the figures practically coincide and have identical character of direction; that is, they extend from northeast to southwest. It may be said in general that in the regions of strongest intensities the greatest absorption was also observed, indicating the presence of softer rays. From the above figures it is seen that the intensity changes sharply with locality, despite the fact that distances between the points do not exceed 12 meters. This change was observed even in those places where absorption by means of filters could not be noticed. On the first map are groups of curves in which the absorption was not noticed, which therefore should not be transferred to the second map. This is to say, there were points at which the rays were so hard that it was impossible to observe their absorption under the conditions of the experiment. Nevertheless, the quantity of these radiations changes sharply from one point to another.

Constancy of Intensity of Penetrating Radiations

Measurements of the intensity of penetrating radiations were made on the same points in the last three years during July and August, for the purpose of determining their constancy. The experiments were made with lead filters 5 mm. in thickness during the daytime and carried out under various meteorological conditions, that is, in quiet and in windy weather and on sunny as well as on cloudy days. The quantity of data obtained at several points characterizing this constancy is shown in Table A.

From the figures of the table it is seen that over a period of three years the variations between values of intensity for the same point did not exceed 3 per cent, hence it may be concluded that the radiation from the earth observed in this experiment is constant for the same place. These verifications also serve to check the constancy of conditions in the observational apparatus during the same period.

TABLE A

Point A (Pyatygorsk)			Point B (Pyatygorsk)		
28 July	1924	12.5	3 Aug.	1925	14.9
28 July	1925	12.3	10 Aug.	1926	15.4
29 July	1925	12.4	11 Aug.	1926	15.3
30 July	1925	12.1			
31 July	1925	12.2			
1 Aug.	1925	12.1			

Digitized by Google

Point C (Pyatygorsk)			Point D (Pyatygorsk)		
30 July	1924	16.5	25 Aug.	1925	8.4
4 Aug.	1925	16.6	26 Aug.	1925	8.6
6 Aug.	1925	16.5	31 Aug.	1925	8.5
13 Aug.	1926	17.0	6 Sept.	1926	8.4
14 Aug.	1926	16.9			

Influence of the Radioactivity of the Atmosphere

The only known factors that could affect the constancy of intensity are the radioactive emanations and products of this disintegration present in the air and on the surface of the earth. At many places the amount of emanation was determined with the aid of a specially constructed apparatus designed by the authors. The principle of this apparatus is to activate a metal rod in a stream of air by the use of a negative potential of 3,500 volts. The air was forced into the apparatus by a fan for 15 minutes at the rate of 70 liters per second. The activated rod was then measured by a sensitive electrometer of the Schmidt type, and the quantity of emanation per cubic centimeter was calculated from the curves of decay produced by the rod. The amount of emanation in the air in the region fluctuated from 36 to 60 x 10^{-18} curie per cubic centimeter. These fluctuations were largely due to the strength and direction of the wind. The connection between these fluctuations and change of place of the total area of 10,500 square meters was not observed. With the above-mentioned fluctuations there can theoretically be produced no influence on the intensity of the penetrating radiations, because the effect would only be noticeable in hundredths of an ion.

Influence of Cosmic Rays from the Surface of the Earth

In the boundaries of the regions where the experiments were carried out the ionizing effect of cosmic radiation should be constant, in which case there should be no noticeable effect from this source in changing from place to place.

Radioactivity of Upper Layers of Earth

The influence of the radioactivity of the earth was frequently measured, and apparently its upper layer had no noticeable influence upon the intensity of the penetrating radiations. The upper layer showed a normal content of hard, gaseous radioactive elements. For a control experiment, measurements were made over a shaft filled with radioactive water having a strength of 70 units Mache. Taking into consideration the volume of water included in the shaft and its radioactivity the amount of emanation was computed and was found to be equivalent to 10^{-7} g. of radium. Measurements of the intensity of the earth's penetrating radiation at this shaft, using lead filters 5, 10, and 15 mm. in thickness, all gave precisely the same value, 13.7 ions. This would indicate that the amount of radium has no effect upon the apparatus. In another control experiment a cartridge containing 1 mg. of radium when placed at the same distance from the instrument showed 200 ions with a lead filter 5 mm. in thickness. From this it may be concluded that the effect of 10^{-7} g. of radium should amount to only 1.02 ions, which is above the sensitivity of the apparatus. Since there was no connection between the radioactivity of the upper layer of the earth and the values

Digitized by Google

obtained with the instruments the supposition is that the basic effect has its source in the harder rays directed from deeper layers. In order to clarify this situation experiments were undertaken to investigate the character of the radiations of the earth. The experiments already described do not offer any possibility of accuracy in determining the influence of such factors as the radioactivity of the atmosphere, side radiation of the earth, and other cosmic radiations. However, the last experiments in August, 1926, were carried out with the apparatus screened not only from the bottom but also from the sides and top.

The experiments of 1926 were carried out in the same region of radium deposits along the crevices of Pyatygorsk. Five points were established in a straight line cutting the group of curves in a direction from West to East. This line was at the foot of a hill consisting of travertines. A sixth point was established in a level place 37 meters south of the main line. These six points were in a region where soft and hard rays were to be found. The absorption of the latter could be noticed with the aid of a lead filter 5 mm. in thickness.

The apparatus was an electrometer which had been used in the previous experiment. It could be placed on a solid wooden table with three legs and furthermore could be screened from above by means of four lead hoods, each fitting into the other and 2 cm. in thickness. The apparatus could be further screened at the bottom by four lead filters of the same thickness but flat in form. The whole weight of lead, totaling 480 kg., was suspended from a specially constructed lifting crane. This method of screening allowed determination of the effect of rays directed not only from the top but also from all sides. The order in which the experiments were carried out was as follows:

The night before the experiments were performed the electrometer was covered on all sides with the four filters and the four hoods. That is, it was surrounded on all sides by 8 cm. of lead. The instrument was screened on the day before the measurements were taken in order to allow equalization of temperature during the night. On the following day, seven measurements were made in the morning with various thicknesses of filters and hoods in accordance with the following table:

No. of measurements	No. of covers	No. of filters
1	4	4
2	4	2
3	4	1
4	4	0
5	2	0
6	1	0
7	0	0

When the measurements were completed the apparatus was again covered with all the hoods and filters and left to stand until the following day. The second series of observations was made in a different order, as may be seen from the following table:

Digitized by Google

No. of measurements	No. of covers	No. of filters
1	4	4
2	2	4
3	1	4
4	0	4
5	0	2
6	0	1
7	0	0

These two series of observations mutually control each another, inasmuch as the results of one series may differ from the results of the other by a constant quantity. For the purpose of plotting curves both the series and the observations were taken into consideration, thereby diminishing the effect of the personal error of the observer and also eliminating repeat errors. For efficient operation it sometimes becomes necessary to replace the lead filters with wooden ones. It was necessary to calculate the coefficient of the absorption with these wooden filters; the thickness used was not 4 but 4.2 cm. With one lead filter 2.3 cm. was used and not 2 cm., etc. The results of these experiments are shown in six tables, giving the mean values found for each point, and the results are plotted in six diagrams (figs. 1, A, B, and 2, A, B, C. D), where the results are expressed in the number of ions formed in 1 cubic centimeter per second. It should be mentioned that at most points the experiments were repeated twice after an interval of a few days; that is, one point was taken, then another, then a third, and then return was made to the first point. If the same results were obtained at this point it might be inferred that in the interval the instrument remained constant. In order to indicate the accuracy of observations the probable deviations of the experimental values found from the curves are presented in the following table:

No. of point	1	2	3	4	5	6
b - $\frac{\text{ion}}{\text{c. c./sec.}}$	0.025	0.13	0.1	0.038	0.024	0.00
C - o/o from q_{min}	.205	1.16	.74	.20	.24	.00

	SERIES 1				SERIES 2			
	Pb, cm.		Intensity, ions		Pb, cm.		Intensity, ions	
No.of measurement	Hoods	Filters	Value found	Ordinates of curves	Hoods	Filters	Value found	Ordinates of curves
	Table 1				Point 1			
1	8.0	8.0	12.19	12.19	8.0	8.0	12.19	12.19
2	8.0	4.2	12.39	12.40	4.1	8.0	12.19	12.19
3	8.0	2.3	12.52	12.53	2.1	8.0	12.25	12.25
4	8.0	0	12.80	12.80	.1	8.0	12.39	12.45
5	4.1	0	12.80	12.80	.1	4.2	12.66	12.65
6	2.1	0	12.95	12.85	.1	2.3	12.80	12.79
7	.1	0	13.10	13.05	.1	0	13.10	13.05

Digitized by Google

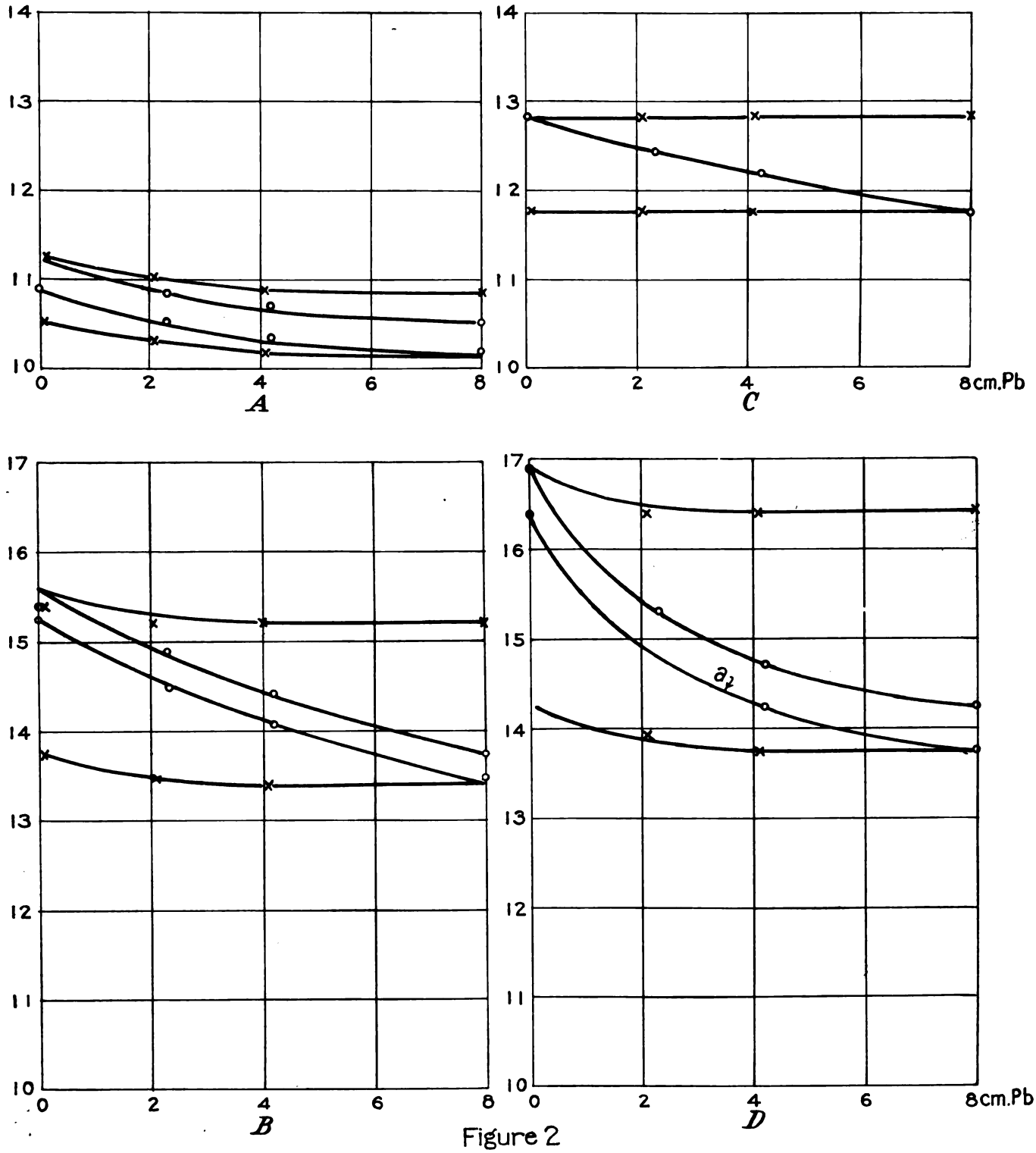


Figure 2

Digitized by Google

	Table 2				Point 2			
1	8.0	8.0	11.23	11.23	8.0	8.0	11.23	11.23
2	8.0	4.2	11.75	11.89	4.1	8.0	11.63	11.65
3	8.0	2.3	12.25	12.57	2.1	8.0	11.69	11.86
4	8.0	0	13.90	13.90	.1	8.0	12.33	12.43
5	4.1	0	14.30	14.20	.1	4.2	13.23	13.10
6	2.1	0	14.55	14.55	.1	2.3	14.07	13.80
7	.1	0	15.10	15.10	.1	0	15.10	15.10
	Table 3				Point 3			
1	8.0	8.0	13.49	13.40	8.0	8.0	13.40	13.40
2	8.0	4.2	14.16	14.10	4.1	8.0	13.40	13.40
3	8.0	2.3	14.52	14.52	2.1	8.0	13.49	13.49
4	8.0	0	15.20	15.20	.1	8.0	13.73	13.73
5	4.1	0	15.20	15.20	.1	4.2	14.43	14.43
6	2.1	0	15.20	15.29	.1	2.3	14.90	14.85
7	.1	0	15.40	15.53	.1	0	15.30	15.53
	Table 4				Point 4			
1	8.0	8.0	13.73	13.73	8.0	8.0	13.73	13.73
2	8.0	4.2	14.22	14.23	4.1	8.0	13.73	13.73
3	8.0	2.3	14.71	14.75	2.1	8.0	13.90	13.85
4	8.0	0	16.40	16.40	.1	8.0	14.24	14.24
5	4.1	0	16.40	16.40	.1	4.2	14.70	14.75
6	2.1	0	16.40	16.46	.1	2.3	15.30	15.26
7	.1	0	16.90	16.90	.1	0	16.90	16.90
	Table 5				Point 5			
1	8.0	8.0	10.17	10.17	8.0	8.0	10.17	10.17
2	8.0	4.2	10.31	10.31	4.1	8.0	10.17	10.17
3	8.0	2.3	10.50	10.47	2.1	8.0	10.31	10.26
4	8.0	0	10.85	10.85	.1	8.0	10.50	10.50
5	4.1	0	10.85	10.85	.1	4.2	10.65	10.65
6	2.1	0	11.01	10.95	.1	2.3	10.80	10.83
7	.1	0	11.23	11.23	.1	0	11.23	11.23
	Table 6				Point 6			
1	8.0	8.0	11.75	11.75	8.0	8.0	11.75	11.75
2	8.0	4.2	12.18	12.18	4.1	8.0	11.75	11.75
3	8.0	2.3	12.45	12.45	2.1	8.0	11.75	11.75
4	8.0	0	12.82	12.82	.1	8.0	11.75	11.75
5	4.1	0	12.82	12.82	.1	4.2	12.18	12.18
6	2.1	0	12.82	12.82	.1	2.3	12.45	12.45
7	.1	0	12.82	12.82	.1	0	12.82	12.82

These are based on both series of observations, and the ordinates of these curves were used to compute the coefficient of absorption.

Digitized by Google

Calling q_{max} the intensity in ions obtained with the apparatus open and q_{min} the intensity obtained with the apparatus inclosed with 8 cm. of lead, a different picture of the results may be obtained from the following table:

Table 7

No. of point	q_{max}	q_{min}	$q_{max} - q_{min}$
I	13.10	12.19	0.91
2	15.10	11.23	3.87
3	15.40	13.49	1.91
4	16.90	13.73	3.17
5	11.23	10.17	1.06
6	12.82	11.75	1.07

Examining the curves plotted from the data of the six tables, it is seen that in all cases of the first and second series the ordinates differ from each other by a somewhat constant quantity in which the filters and the hoods were altered.

After the thickness of the lead has attained 4 cm. the curves for the absorption of the hoods almost always tend to become parallel to the axis of the abscissas; that is, the soft radiations from the side have all points absorbed. Point 2 presents an exception where complete absorption was not obtainable even after an 8-cm. lead filter was used. Point 6 is also an exception, where no absorption was noted. The curves of absorption from radiations from below change character sharply, depending upon the place where the measurements were carried out. From these data it is possible to compute the coefficient of absorption with lead.

Calculation of Coefficient of Absorption

Given three points upon the expotential curve having for its asymptote a straight line, $I=q_0$ (fig. 3) than this quantity, as in the case of simple radiation, will represent the ionization of the apparatus. The following conclusions may now be written:

Digitized by Google

$$I_1 - q_o = (I_o - q_o)e^{-\mu x_1}$$

$$I_2 - q_o = (I_o - q_o)e^{-\mu x_2}$$

$$I_3 - q_o = (I_o - q_o)e^{-\mu x_3}$$

From which $$\frac{I_1 - q_o}{I_3 - q_o} = e^{-\mu(x_1 - x_3)} = e^{\mu(x_3 - x_1)} \qquad (1)$$

From (1) we have $$\frac{I_2 - q_o}{I_3 - q_o} = e^{-\mu(x_2 - x_3)} = e^{\mu(x_3 - x_2)} \qquad (2)$$

From (2) $$\frac{I_1 - I_3}{I_3 - q_o} = e^{\mu(x_3 - x_1)} - 1 \qquad (3)$$

$$\frac{I_2 - I_3}{I_3 - q_o} = e^{\mu(x_3 - x_2)} - 1 \qquad (4)$$

From (3) and (4) $$\frac{I_1 - I_3}{I_2 - I_3} = \frac{e^{\mu(x_3 - x_1)} - 1}{e^{\mu(x_3 - x_2)} - 1} \qquad (5)$$

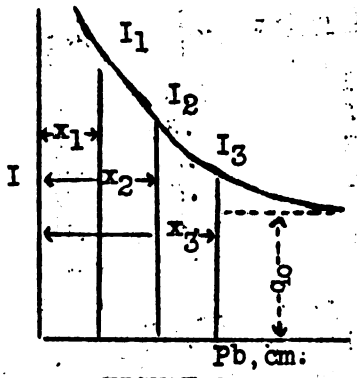


FIGURE 8.

In equation (5) the differences x_3-x_1, x_3-x_2, I_1-I_3, and I_2-I_3 are known, and from the calculations the unknown value of μ can be determined.

This method of computing the value of μ depends only upon the character of the curve and is in no way connected with the determination of q_o - the ionization of the apparatus. The experimental determination of this would involve great difficulty and it is also difficult to be certain of its constancy. Inasmuch as there are four points for each curve formula (5) may apply in three parts for the determination of μ as follows:

<u>For filters</u>

0.0 2.3 4.2 cm. .....(μ_1)

2.3 4.2 8.0 cm. .....(μ_2)

.0 4.2 8.0 cm. .....(μ_3)

Digitized by Google

For Hoods

0.1 2.1 4.1 cm. .....(μ_1^1)

2.1 4.1 8.0 cm. .....(μ_2^1)

.1 4.1 8.0 cm. .....(μ^1)

Calculated values for are given in the following table:

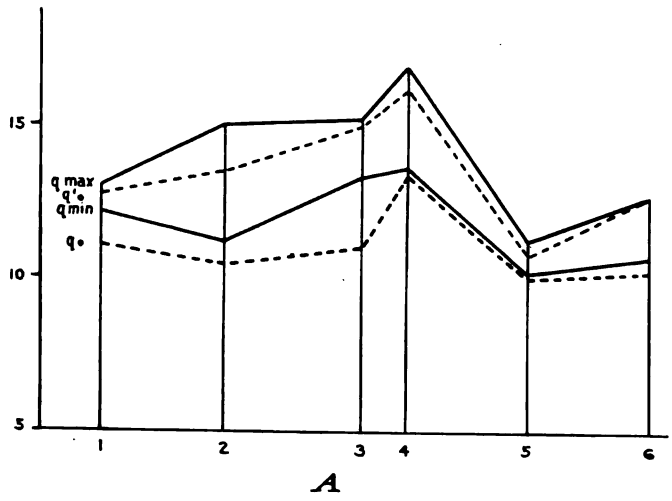
Table 8

	For hoods (side and top radiations)			For filters (lower radiations)		
No. of point	μ_1^1	μ_2^1	μ^1	μ_1	μ_2	μ
1	0.6	-	-	0.25	0.08	0.13
2	.33	0.18	0.23	.23	.25	.24
3	.5	-	-	.18	.07	.085
4	.6	-	-	.45	.27	.33
5	.47	-	-	.365	.31	.32
6	-	-	-	.08	.06	.075

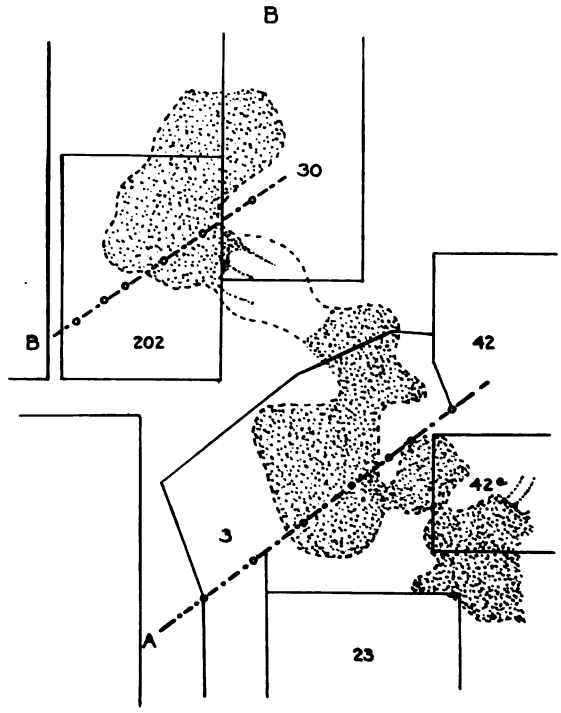
It is necessary to note that the calculations of the coefficient of absorption, especially for the hoods, are to some extent conditional, inasmuch as the above formulas apply to a parallel pencil of radiations directed normally to the absorbing surface. Examination of Table 8 indicates that when hoods were used the coefficient of absorption differed only slightly from that of the γ rays of radium C. In view of the fact that the first five points were established at the very base of the hill and the last one some distance away, it may be supposed that the side radiations which depend upon the contour of the region have an effect. On the other hand, point 6 is on a level place where the effect of side and top radiations is not observed. By investigating the radiations from below with flat filters an entirely different picture is presented. Inasmuch as the value of μ changed from 0.45 to 0.06 for lead the effect of radiations having a greater penetrating ability than γ rays of radium may have been encountered. These radiations do not appear to be simple, since the effect of increasing the thickness of lead causes μ to disappear.

From equation (2) it is possible to compute the value of q_o, using μ as a coefficient of absorption. The fluctuations in the value of q_o will characterize the amount of radiations of strongly penetrating qualities, even more so than the variation of μ in different places. The values of q_o at various points are given in Table 9, as follows:

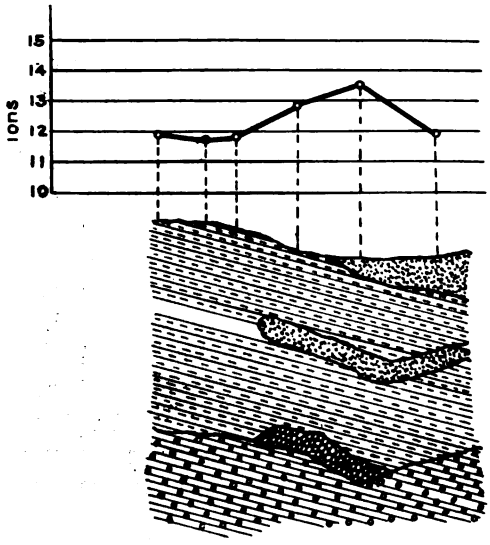
Digitized by Google



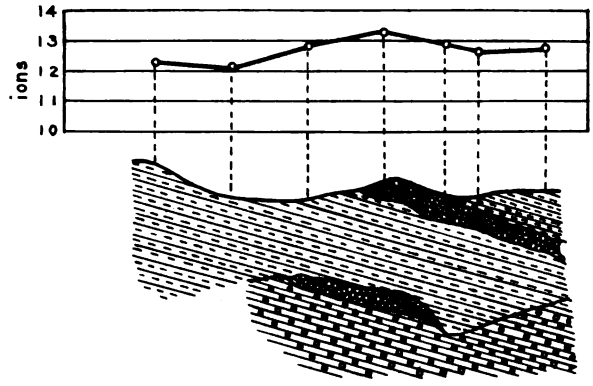
A



C



B



D

Figure 4

Digitized by Google

Table 9

No. of points	1	2	3	4	5	6
	11.1	10.47	11.1	13.5	10.1	10.45

It can be seen that the values of μ and μ_2 vary with change of place, and it is to be noted that the softer radiations observed at point 4, at an earth crevice, contained deposits of radium very close to the earth's surface. In Figure 4, A (p.) can be seen the fluctuations of q_{max} and q_{min}, q_o and q_o^1, where the last term represents the intensity at complete absorption of top and side radiations. Although the distance between points 1 and 5 was taken at a definite scale the distance between 5 and 6 was chosen arbitrarily, inasmuch as point 6 was not on the line.

Calculations of the length of the wave, using the coefficient , can be calculated from the formula $\mu = \left(\frac{\sigma_0}{1 + 2\,\frac{0.0242}{\lambda}} + \beta\lambda^3 Z^3\right)\frac{2NP}{A}$, where μ = the coefficient of absorption; $\sigma_0 = 6.64 \times 10^{-25}$; $\beta = 2.24 \times 10^{-2}$; Z = the atomic number = 82; A = the atomic weight = 207.2; N = Avogodro's number = 6.06×10^{-23}; and p = the density = 11.3.

Calculations are not shown, but the values given in the table are the length of waves expressed in A.U. in which the same characteristic markings are applied to λ as were applied to μ in Table 8.

Table 10

No. of points	1	2	3	4	5	6
	11.1	10.47	11.1	13.5	10.1	10.45

From this table it is seen that at point 6 radiations were encountered whose wave length was 0.00165 A.U., which is 12 times harder than the γ rays of radium C (0.02 A.U.) and only 4 times softer than those observed by Millikan at Mura Lake in California. It may be supposed that with a greater thickness of lead it would be possible to investigate radiations of even shorter wave lengths.

Investigations of the type described above indicating the existence of strong penetrating earth's radiations were made in other places. It was always possible to observe the constancy of the intensity. For instance, in the garden of Pavlovak Geophysical Observatory (near Leningrad) on various days, the following values were obtained for q_{max}: 8.45, 8.67, 8.57, 8.48, and 8.45 ions. A table is now given which represents the general summary of all the observations carried out with the same apparatus. Here the values of q_{max}, that is, with the apparatus unshielded by lead, are recorded in Table 11, as follows:

Digitized by Google

Table 11

Caucasus.	Region of travertines with deposits of radium	11.2 - 22.7
Caucasus.	Summit of Mashuska. Senon limestone.	11.2
Kuban region.	Clays.	11.7 - 13.5
Leningrad.	Main building of Weights and Measures, in building.	9.4
Pavlovsk.	Garden of the Geophysical Observatory.	8.5
Leningrad.	On the ice of the River Neva.	7.4
Leningrad.	The Institute of Applied Geophysics.	7.9
Leningrad.	In private house. Before leaving for Caucasus.	7.4
Leningrad.	In private house. Upon returning from Caucasus.	7.6

In the Institute of Applied Geophysics there were observed radiations which were much harder than γ rays of radium C, according to the following:

$\mu_1 = 0.24$ $\quad\quad$ $\lambda_1 = 0.0070$
$\mu_2 = .12$ $\quad\quad$ $\lambda_2 = .0034$
$\mu_3 = .15$ $\quad\quad$ $\lambda_3 = .0045$

These experiments were carried out with hoods and filters up to thicknesses of 8 cm., and the absorption of the hoods was not noticed, but the coefficient of absorption of the bottom filters corresponding to the wave lengths was recorded.

From all these figures it can be seen that the intensity of the penetrating radiations close to the earth's surface varies within wide limits and apparently depends directly upon the concentration of radioactive elements in a given place. It is supposed that the harder rays were encountered in consequence of considerable masses of radioactive material. Under these conditions the relative amount of hard rays increases because with increase in hardness the active volume has also increased. The experiments described above are not exhaustive, and it is desired to carry out some more having for their aim a more complete investigation. The work has been carried out by the help of the Institute of Applied Geophysics, with close participation of the Main Chamber of Weights and Measures, whose cooperation is appreciated.

1. Measurements of penetrating radiations from the earth made at Pyatygorsk (in the Caucasus) by means of a portable electrometer covered with lead 1 cm. in thickness have shown that although the same apparatus had been used the intensity fluctuated greatly, depending upon the observation stations where the measurements were made. The fluctuations of intensity were specially marked in places rich in radium, where divergences of no less than 100 per cent were observed between stations separated by only a few meters.

2. Measurements made at the same observation stations during a period of three years have shown the intensity to be constant and to be independent of meteorological conditions and fluctuations of emanations in the atmosphere, in the limits of sensitiveness of the apparatus.

Digitized by Google

3. Measurements of the radioactive elements in the upper layers of the soil have shown their constancy, which permits the supposition that the fluctuations are probably due to deeper strata only.

4. The use of four hoods fitting each other, 2 cm. thick and covering the apparatus from above and laterally, and of four lead flat screens protecting it from beneath has shown the influence of the hoods to be very slight and that of the screens very important, thus testifying to the electrometer being acted upon chiefly from below.

5. The thickness of lead protecting the apparatus from above, from the sides, and from below having been varied from 0 to 8 cm., computation of the coefficients of absorption was rendered possible. As it appeared, the coefficients of absorption by screens varied from 0.45 to 0.06 for 1 cm. Values approaching the lower limit were frequently noted at different stations. In most cases the height of the coefficient of absorption diminished as the thickness of the lead screens increased; that is, a complex of radiations was here dealth with, some of them possessing a much greater radiating capacity than the γ rays of radium C. The radiations are directed from below and their source may be understood to lie in radioactive elements diffused in the upper strata of the soil.

RADIOMETRIC EXPLORATION OF OIL DEPOSITS[3]

By L. N. Bogoiavlensky

In the article "Experiments with Strongly Penetrating Radiations from the Earth" measurements of the intensity and character of penetrating radiations in connection with the geology of the region, extending over several years, were summarized. At present, it can be considered a fully established fact that the intensity of penetrating radiations from the earth changes sharply, depending upon the places where the observations were made, particularly those rich in radium, where the fluctuations attained 100 per cent between points separated from each other by only a few meters. Measurements at the same points continued over a period of three years show no variation of intensity and its independence of meteorological conditions, as well as variations in the contents of emanations in the air. In the summer of 1926 a study was made of the character of radiations with an electrometer screened on the sides and top with lead hoods of a thickness up to 8 cm. and on the bottom with flat lead filters of the same thickness. By these means it was established that the main portion of the radiations comes from below. With the use of these same lead filters it was possible to determine the coefficients of absorption of radiations directed from below. Thus the existence of a "complicated complex" of the earth's radiations was established with the coefficient of absorption by lead varying from 0.45 to 0.06 per centimeter; that is, part of it had a penetrating capacity 12 times greater than the γ rays of radium C.

---

3 - Translated from the Russian by A. Seletzky.

Digitized by Google

From these experiments it may be concluded that the intensity of penetrating radiations depends upon the degree of concentration of radioactive elements in the earth's core. If it is presupposed that radium gives a very negligible amount of radiations of long wave lengths and much more of the shorter, the presence of hard radiations observed can be explained, which, coming from enormous masses of weak radioactive substances, reacted upon the apparatus. Under these conditions the relative amount of hard rays increases, because with increase in hardness the active volume increased. Consequently, in the use of a radiometric method of exploration there must be kept in mind very accurately the contests of radioactive elements in the ore body and in the strata comprising it, because a minute change of contents has an appreciable influence upon the change of intensity of the penetrating earth radiation.

The radioactivity of oil deposits is differentiated from the radioactivity of strata comprising it, according to the following conditions:

1. Oil as an organic compound possesses an enormous power of absorbing radioactive emanations.

2. The layers underlying the oil bed which represent repositories of sea-ooze are richer in radium because of the great absorbing power peculiar to colloids.

These two conditions allow the consideration of an oil deposit as richer in radioactive elements than the clay strata containing it. Contemporary literature, although supplying extensive information on the contents of radioactive elements in water of springs, streams, and seas, has meager data on natural organic bodies, in which class oil belongs. The following explanation may suffice: In the first place, the curative properties of waters of springs containing solid and gaseous radioactive elements excited an interest in them that had a purely practical aim; and in the second place, difficulties accompany the determination of the radioactivity of oil, which has an enormous absorbing power for radioactive emanations. These difficulties are largely due to the impossibility of separating the radioactive gases from the oil at ordinary temperature and the necessity of using special apparatus, which is difficult to manipulate under field conditions.

The first measurements of radioactivity of water sources and of oil were made by Himstedt in 1904. J. J. Thomson first established the presence of radioactive emanations in them. Himstedt[4] found emanations in the Freyberg springs and in sources of oil. Traudenberg,[5] studying the emanations in the same Freyberg springs and in sources of oil, concluded that all the laws on the solution of gases in liquids can also be applied to them. This author gives a value for the coefficient of absorption of emanations of radium by water. Mache[6] and Hoffmann[7] obtained very close values to these. Later, Kofler[8] gave a value for the

4 - Ann. Phys., 1904.
5 - Physikal. Ztschr., vol. 5, 1904, p. 130.
6 - Wien Ber. vol. 113, 1904, p. 1329.
7 - Physikal. Ztschr., vol. 6, 1905, p. 337.
8 - Physikal. Ztschr., vol. 9, 1908, p. 6.

Digitized by Google

coefficient of solubility of the emanations of radium in aqueous solutions of salt, and Boyle[9] proved the law of Henry in regard to the solubility of the emanations of radium. In this way the above-mentioned authors established the fact of the presence of radioactive emanations in natural liquids. Rumstedt[10] made determinations of coefficients of absorption for many liquid and solid organic compounds, from which it is known that the materials having the greatest powers of absorption are oil, paraffin, xylol, toluol, hexane, and carbon bisulphide. The following table, from the table of Hoffmann, gives an idea of the magnitude of the coefficient of absorption of radioactions of radium in water and oil at different temperatures:

Temperature, ^{o}	Water	Oil
21	-	22.7
2	0.245	12.87
20	.23	9.55
40	.17	8.13
60	.135	7.01
70	.12	-
80	.12	-

From this it is seen that at 3^{o} the coefficient of absorption of oil is 81 times, at 20^{o} 45 times, at 40^{o} 48 times, and at 60^{o} 52 times greater than water. The relative absorbing power of oil for emanations is clearly seen from this table.

Burton[11] made measurements of the radioactivity of oil at Petrolia, Ontario. The sample was taken at a depth of 465 feet under the surface of a limestone stratum. The radioactive gas dissolved in the oil was found to be an emanation of radium. Unfortunately, under this condition indications were lacking of the quantity of emanations in the oil.

The Rumanian investigator Hurmuzescu[12] draws the following conclusions after investigating several oil wells in Rumania.

1. The oil of the Campina-Bustenari region and of Parjol-Moinesti is radioactive in consequence of the presence of radium emanations.

2. In the same region oil from various "crevices" containing boron or wells can have a varying radioactivity, depending upon the region and the physical properties of the oil. Light oil has been found to be more active.

3. For the same "crevices" the radioactivity of the oil is always greater during the first flow of the oil wells.

---

9 - Phyl. Mag., vol. 22, 1911, p. 840.
10 - Le Radium, vol. 8, 1911, p. 263.
11 - Physikal. Ztschr., vol. 5, 1904, p. 511.
12 - C. R. Congre. Int. Radiol. et Electric., Brussels, 1910.

Digitized by Google

4. Gases which separate out from the "crevices" upon exploitation are always less radioactive than the oil itself. The salt water from the crevices is even less radioactive than the gases.

In conclusion, the work of Mache and Hoffman should be mentioned; they took advantage of the absorption characteristics of kerosene for determining the absolute contents of emanations of radium in atmospheric air. It may be seen from the preceding that all the above investigations are unsystematic, and no efforts were made to take advantage of the radioactive character of oil when exploration was under way. However, in the last two or three years this question has become important. Judging from the little data available in literature[13] the work of this investigation in this direction is going forward, but the results and even the methods used for this kind of exploration are kept secret. Ambronn[14] gives the only concrete description of a method of exploration which apparently uses the ordinary electroscope for measuring the radioactivity of deposits and of waters in springs; the results obtained with this method are also given. In his book are to be found cross sections of oil "crevices," samples of which were carefully studied by him in respect to their radioactivity. Pyrites gave the minimum radioactivity. An enormous increase in radioactivity was observed at two different horizontal strata in the top layer of sandstone clays lying beneath the oil-bearing sand.

Indications are that the only proper way to make investigations of this sort is to study strongly penetrating radioactive emanations of the earth. Measurements of such emanations, in view of the fact that they are connected with enormous masses of materials, are less difficult to make than the ordinary measurements of samples having faint activity. Under field conditions the measurements are not complete and do not allow evaluation of the fundamental problem in a radiometric exploration.

For the experiments in radiometric exploration of oil deposits in 1924 the Maikopsky field was chosen because it had an undisturbed tectonic and was well known and investigated geologically. The investigations were purely experimental. The Maikopsky field occupies an enormous surface in a virgin region covered by forest. For the experiments, two lines cutting the oil deposit transversely were made. The region in which the work was done was studied in detail by I. M. Gubkin[15] and K. A. Prokopof, geologists.

The Maikopsky deposit, which is in the form of a sleeve and contains light oil, is by its structure readily adaptable to radiometric experiments. Here an undisturbed tectonic and oil-sand strata were found to be present.

In the whole region there were deposits of two kinds of oil--a top heavy oil with a density of 0.920, having a plastic character, and a lower light oil with a density of 0.840 with foranimiferous clays underneath. The lower light

13 - Rick, Maurer, Petroleum, Apr., 1926.
14 - Ambronn, Angewandte Geophysik, 1926.
15 - Gubkin, I. M., Proc. Geol. Comm., Nov. 28th series of issue.

Digitized by Google

oil occurs in small lakes, apparently not connected. In a commercial sense the deposit of light oil is of greater interest than the heavy oil.

The maps prepared by Gubkin have no commercial value at present because this region has been practically worked out. In the last 10 years the center of activity has been carried far north. Nevertheless this field, as the best known geologically, was chosen for radiometric observations.

The order in which the work was carried out follows:

1. A line was drawn (fig. 4, B) with points at definite intervals constituting a section according to the data of Gubkin, then measurements of penetrating radiations were made at these points. The lines were chosen in such a way that they would cut the deposit of oil traversely. Inasmuch as rather small fluctuations of intensity in penetrating radiations were observed, the measurements were made with special care, enough to assure an accuracy of 0.2 ion.

Every point was measured and checked frequently for several days, and the figures were found to be constant. Absorption with increase in thickness of the lower filters was not noticed at any of the points, which showed that there were present only strongly penetrating radiations, upon which a 1-cm. thickness of lead had no noticeable influence.

The position of the line cutting the deposit of light oil transversely is shown in Figure 4, B.

The line A is on the southern boundary, plot 3, on the right bank of the Chekoch River, and contains seven points. Line B, plots 202 and 30, passed through the "boric crevice" M at an angle of 55° N. and has six points. Both lines passed through heavy and light oil in various combinations, as may be seen from cross sections.

A general summary of the results of the experiments in the Maikopsky field may be obtained from the following table:

	Ions
Line A. Point 1	12.3
2	12.1
3	12.8
4	13.3
5	12.9
6	12.7
7	12.7
In Litovchenko house. Oil absent.	12.0
In hospital.	11.8
Line B. Point 1	11.9
2	11.7
3	11.8
4	12.8
5	13.5
6	11.9

Digitized by Google

The accompanying diagrams of the two cross sections (fig. 4, C and D) and the intensities show clearly enough the sharp increase of intensity of penetrating radiations above oil deposits, which is far beyond the limits of errors in observation. It may be noticed at the same time that the heavy oil caused an increase in intensity just as much as did the light oil

The experiments on radioactivity of oil using Schmidt's apparatus did not give, as may be expected, any concrete results. This was due to the inability of the Schmidt equipment to allow heating of the oil to boiling when measurements are made.

Summary

The intensity of penetrating radiations originating in the earth depends mainly on the degree of concentration of radioactive elements in the core of the earth. Our latest experiments in the study of emanations of the earth lead to the supposition that the radium dispersed in the core of the earth yields a certain amount of emanations of much shorter waves than those previously admitted. The slightest change of radium content in ores must therefore be reflected in the intensity of penetrating radiation:

The radioactivity of an oil bed must differ from that of the strata inclosing it on the following grounds:

1. Oil, being an organic compound, possesses an immense power of absorbing radioactive emanations.

2. The layers underlying the oil bed, having been developed from repositories of sea-ooze, are richer in radium because of the greater power of absorption peculiar to colloids.

The oil bed must therefore be richer in radioactive elements than the embedding clay layer.

The experiments of the Radiometric Subsection of the Institute of Practical Geophysics with the oil deposits of the Maikovsky district, in the Kuban government, have shown that penetrating radiations increase above oil lenses of light naphtha as well as above strata of heavy oil.

SOME MEASUREMENTS OF THE RADIOACTIVITY OF GASES AND WATER OF THE UKHTA OIL-BEARING REGION AND OF MEDICINAL MUD AND BRINE FROM THE SALT LAKE OF THE TINAKEE STATION

By A. Cherepenikov[16]

In the summer of 1926 the author made studies of natural gases of the Ukhta and the Ural-Embensky regions. Under the authorization of the Institute of Applied Geophysics several measurements were made of the radioactivity of natural gases, waters, brine, and medicinal mud.

16 - Translated from the Russian by A. Seletzky.

Digitized by Google

For the measurements of radioactivity the emanation apparatus of Schmidt was used. The measurements did not pretend to be accurate, inasmuch as they were made under unfavorable field conditions. In regard to the determination of the radioactivity of water, the limits of accuracy are especially lowered as a result of a series of errors in the calibration of the apparatus. For this reason the figures given in the article should only be considered an indication of the degree of radioactivity.

At the surface the Ukhta region consists of strata of the Devonian period, which formed a large, gently sloping cupola fold directed north-northwest. Investigations on boron in the past have established the facts that the underlying strata are large layers of gray slate older than the Devonian. Above these lies a Devonian sublayer of oil-saturated clay slate, and below the oil deposit some oil and gas bearing horizontal strata also occur. On its sides lie layers of combustible slate and oil-saturated clay slate, and similar strata are above it. Strata of more recent date are to be found outside the periphery of the oil-bearing region. No tectonic disturbance of the structure of the strata was encountered. However, one of the deposits of boron (Voronov on the Yager River) struck a plastic vein of diabase at a depth of about 50 meters.

Most characteristic of the waters of the region are the following:

1. Oil-saturated clay slate, bitter salt water with H_2S content.

2. Water from a deep stratum of oil-saturated clay slate attached to gray slate and to the lower stratum of oil-saturated clay slate was found to have a large content of salt (about 3°/$_{00}$) at a temperature of about 7°.

In the Ukhta oil-bearing region determinations were made of two gases and two waters as to their radioactivity.

1. On July 10, 1926, the gas from the deep "crevice" of the Russian T-va, "Oil," just at the point where the Tziby River enters the Ukhta River, was found to be not radioactive. The depth at which the gas separates is not known, inasmuch as it is not known how far down the pipes were let into the "crevices." They had, however, an initial depth of 478 meters and were established in gray slate.

2. Measurements were made of the gas in the water which emanated simultaneously from the Government's "crevice" N° on the Ukhta River. Accurate depths of the gas and of the water were not available. The "crevice" went down 427 meters and penetrated gray slate. The gas showed strong radioactivity and was measured twice. The results of these two measurements differed from each other considerably.

3. The figure taken upon June 30, 1926, for the first value was 55 units Mache, and the second, taken July 12, 1926, was 22 units Mache. The water from this same "crevice" was measured July 2, 1926, and had a radioactivity of 3.5 units Mache. This water is highly mineralized and contains 50 gr. of dry matter per liter.

Digitized by Google

4. The water from the "crevice" on the right bank of the Krohal River 1 verst (0.66 mile) from the mouth characterizes the waters of the Domanik (oil-saturated clay slate) stratum, being slightly mineralized, with a strong odor of H_2S. Measurements show that this water is not radioactive.

5 and 6. Work was also done at the Tinakee station near Astrachan. Measurements of the radioactivity (1) of brine and (2) of medicinal mud from the Salt Lake were made on August 22 and 23, 1926. Both of these measurements within the limits of accuracy of observations showed an absence of radioactivity.

SUPPLEMENTARY INFORMATION ON RADIOACTIVE SUBSTANCES AND METHODS FOR DETERMINING THEIR LOCATION

By F. W. Lee[17]

Radioactive indications were first used for determining the location of ores containing a high amount of radioactive substances and for determining radium emanations in springs used for medicinal purposes. The method of detecting radioactive substances is relatively simple and has been developed in several directions. Speculation as to the geological evolution of the earth strata has, to some extent, been based on the amount of radioactivity now present in various rock formations.

Properties of Radioactive Substances and their Determination

A comprehensive summary of radioactivity is given by Meyer and Schweidler, Heresy and Peneth, Curie, Rutherford, Muller-Pouillet, Makower, and Geiger and Makower. Radioactivity of the soil and in springs is carefully considered by Gockel. Rutherford and Soddy clearly demonstrated that radioactive disintegration products were produced from the original radioactive substances. This decomposition occurs in steps, sequential and often overlapping, and is accompanied by the freeing of a large amount of energy. Because of the energy characteristic of these substances their existence can be determined. In addition to the positively changed helium atom consisting of α rays, electrons or β rays and γ rays or hard X-rays are present.

There is associated with radioactive phenomena a characteristic transition constant which may be described as follows: Consider a group comprising a very large number of atoms, all of which at some time or other are compelled to go into radioactive decay, yet only a certain number are in this process at a given time. The rate at which this decay is taking place or the number per second undergoing radioactive change is always directly proportional to the number of atoms under observation. This proportionality factor is λ.

To those familiar with the conventional calculus it may be stated as follows:

17 - Senior physicist, Bureau of Mines.

Digitized by Google

Let N = number of atoms present subject to radioactivity at time t

Let $\frac{dN}{dt}$ = rate at which the number is changing

then $\frac{dN}{dt} = -\lambda N$ expresses the above facts.

This may be represented by the well-known curve of Figure 5, $N = N_0 \epsilon^{-\lambda t}$ between time and number of atoms.

N_0 = initial number of atoms and is

ϵ = the base of the natural logarithms.

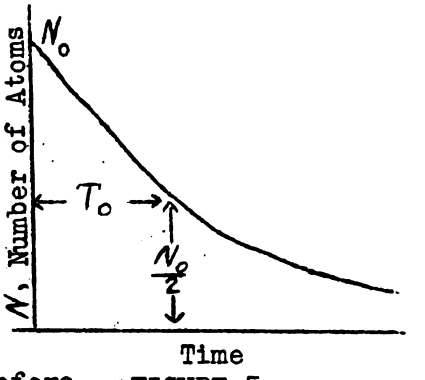


FIGURE 5.

Although the equation of the curve is assymptotic to the horizontal axis actually the number at some time becomes zero or the curve is good only when n is comparatively large. Rigorously the curve is a stepped curve, and the limiting conventional mathematical ratio $\frac{\delta N}{\delta t}$ is not permissible. and only when $\frac{\Delta N}{\Delta t} = \frac{1}{\Delta t} = \frac{\delta N}{\delta t}$ is the solution valud. This equation therefore is (only the limiting approximation) for the first part of the curve.

If N_0 in the above figure is the original number and after a time, T_0, the number has been reduced by radioactivity to $\frac{N_0}{2}$ or the element has lost one-half of its original activity, then the time T_0 is called the binary time constant (Halbierungszeit) and is inversely proportional to λ. The following is a short table of radioactive elements compiled by Ambronn:

Material	T_0 = Binary time constant		Rays
Uranium	5×10^9	Years	α
Ionium	10^5	Years	α
Radium	1750	Years	α, β
Radium emanation	3.86	Days	α
Radium A	3.05	Minutes	α
Radium B	26.8	Minutes	β, γ
Radium C	19.6	Minutes	α, β, γ
Radium D	about 16	Years	β, γ
Radium E	4.86	Days	β, γ
Radium F	136	Days	α
Lead	Stabil		-

Digitized by Google

Uranium	5×10^9	Years	α
Actinium	about 30	Years	α
Actinium emanation	3.9	Seconds	α
Actinium A	.002	Seconds	
Actinium B	36.1		β, γ
Thorium	1.8×10^{10}	Years	α
Thorium X	3.64	Days	α
Thorium emanation	54.5	Seconds	α
Thorium A	.14	Seconds	α
Thorium B	10.6	Hours	β, γ
Thorium C	60.4	Minutes	α, β

From which is seen that α or helium occurs quite often and the time of decomposition varies from the order of 0.002 second to 1.8×10^{10} years. There is also some radioactivity in the alkalies of low atomic weights. Calcium and rubidium are also slightly radioactive. The radioactivity of the alkalies is considered in the work of Elster and Geitel, Hahn and Rothenbach, Neuburger, and Hoffman. The radioactivity of all matter has been considered by Hoffman and Kolhorster.

Penetration of radioactive rays is different for each radioactive substance, and the associated energy is also a characteristic of each ray. The penetration for the α particle is measured in air and is of the order of 5 cm. and in the case of thorium C exceeds 8 cm. The ionizing power of the α rays is very great; one α particle has energy enough to generate 190,000 ions. The penetration of the β rays is measured by the absorption of aluminum foil. The thickness of foil which will reduce the intensity of rays by one-half is generally taken as the unit. The γ rays of thorium D will penetrate 7.22 cm. of aluminum or 1.5 cm. of lead.

Radioactive substances may be measured in the following ways:

1. Photographic methods
2. Ionization methods
3. Calorimetric methods

The oldest method was probably the use of the photographic plate. The latter is exposed to radioactive minerals separated from the plate by proper screens. Levin and Ruer, and Greinacher, give results with various photographic plates and their reaction to radioactive substances. Photometric means are used to compare relative intensities in the photographic plate. The method has the great recommendations of simplicity and cumulative action derived by the length of time to exposure. The methods most frequently used are based upon the ionizing power of the α, β, and γ rays. These rays have the power to ionize neutral gases into positive and negative ions. By exposing these ions to an electric field strong enough to remove them as fast as they are formed, a saturation current is obtained. The strength of this saturation current is an index of the ionization present and therefore also of the amount of radioactivity.

Digitized by Google

Radioactive Equilibrium: If a radioactive compound exists with its decomposition products in such a way that new radioactive atoms per unit time are formed to replace exactly those that decay, then there is a condition of radioactive equilibrium.

Radium Emanation: A gas emitted from radioactive substances having an atomic weight of about 200.

Curie: A unit of emanation, representing the amount of radium emanation in radioactive equilibrium with 1 gram of radium. At 0^{o} and 760 mm. pressure the unit occupies a space of about 0.6 $\frac{3}{\text{mm.}}$ and weighs 6×10^{-6} grams. The number of atoms in 1 curie is about 1.7×10^{16}, and the energy liberated in complete decomposition is 38.60 calories.

Mache Unit: The amount of emanation in 1 liter which will produce a saturation current of $\frac{1}{1,000}$ electrostatic units of current. Although this unit seems rather extant actually it can be very readily applied. In an electroscope or electrometer--

Let V_1 = voltage in magnetic units (ordinary voltmeter) before discharge of electrometer.

V_o = voltage at end of discharge of electrometer.

t = time interval of observation.

C = electrostatic capacity in centimeters (the variable effect of the needle is often neglected and only the electrostatic capacity of the ionization chamber is usually used).

I = saturation current in electrostatic units.

Then $I = \frac{(V_1 - V_o)\ C}{300t}$

The number of Mache units (M.U.) = 1000 I.

Hence $\text{M.U.} = \frac{10}{3} \frac{(V_1 - V_o)\ C}{t}$

The needle is usually calibrated from a battery, and the capacity may be measured by the method of mixtures.

Experimental evidence shows that the radioactivity of radium emanation in equilibrium with 1 gram of radium indicates a saturation current of 2.5×10^{6} electrostatic units, equal therefore to 2.5×10^{9} M.U. Hence $\underline{1\ \text{M.U.}} = \underline{4.10^{-10}}$ Curie units.

Digitized by Google

If it is desired to compute the current in terms of amperes as measured by a galvanometer the electrostatic units of current must be divided by 3×10^9. The current I in this case becomes $I = \frac{(V_1-V_0)\ C}{300t} \times \frac{1}{3 \times 10^9} = \frac{1.11\ (V_1-V_0)\ C}{t}\ 10^{-12}$ amperes.

Since the most delicate galvanometers, except the Einthoven string galvanometer, measure magnitudes of the order of 10^{-9} amperes it is seldom feasible to use instruments of this character.

For purposes of geophysical prospecting it is only necessary to compare the time intervals for the electrometer needle or threads in the electroscope to fall to the same position. Certain refinements are possible, as allowing the charge to fall to zero and build up again with reversed polarity, thereby eliminating any uncertain zero in the apparatus.

For example, let the activity of a standard condition be denoted by N_s and the time to discharge to a certain voltage V_0 from V_1 be t_s. Let N be the radioactivity of the unknown and let t be the time to reach the same voltage V_0 from V_1. Then the following relation from the previous formula is evident:

$N_s t_s = Nt$ or $N = N_s \frac{t_s}{t}$ Hence the ratio $\frac{t_s}{t}$ is the index number of comparison between the two conditions stated.

For measuring the current a bifilar electrometer or electroscope designed by Wulf is used. It consists essentially of an ionization chamber into which the radioactive substance is introduced. Ambronn has very recently designed an Emanations-Elektrometer especially adapted for geophysical exploration work, a detailed description of it may be found in Physikalische Zeitschrift, No. 12, June 15, 1927. Holes are made in the ground for receiving samples of air from the ground. The radioactive air is pumped by a small hand pump into the ionization chamber of the instrument. Special precautions must be taken to avoid condensation of moisture upon the insulation; a small heating unit generally suffices. Kolhorster has designed instruments suitable for inserting into a drill hole and measuring the radioactivity by the γ rays.

Relation of Radioactivity to Geophysical Prospecting

There is a certain amount of breathing at the surface of the ground due to change of barometric pressure. This tends to dilute the normal concentration of emanation to a depth of from 4 to 6 meters.

A portion of the upper strata of ground and part of the radioactive material in the air emit a very hard γ ray. About one-third of this penetrating ray comes from above. These rays are measured by their ionization power in vessels lined with zinc. Kolhorster has made numerous improvements in measuring these rays by increased ionization and also with photographic registration. The variations of these penetrating rays have been recorded by Hoffmann, Hess and Kofler, and Kolhorster.

Digitized by Google

According to Bogoiavlensky these rays have a deep source, whereas others claim that the rays are from a comparatively shallow depth. They have the advantage of being able to detect very slight amounts of radioactive material.

There are in general two methods available for checking radioactive material.

1. By an ionization chamber exposed to γ radiations.

2. From air extracted from ground carrying emanations. The former method is simpler but not quite as sensitive. The latter method requires considerable auxiliary apparatus. Both methods should be checked against each other. (See v. d. Borne and Winnacker).

The districts containing radium deposits have been described by Petraschak and Krusch. The amount of radium and thorium in unweathered rock is given by Kolhorster as follows--gram per gram:

Acid rocks	Volcanic origin	3.1×10^{-12}	radium	3.5×10^{-5}	thorium
	Plutonic origin	2.7×10^{-12}	radium		
Intermediary rocks	Volcanic origin	2.1×10^{-12}	radium	1.7×10^{-5}	thorium
	Plutonic origin	1.9×10^{-12}	radium		
Basic rocks	Volcanic origin	1.1×10^{-12}	radium	$.5 \times 10^{-5}$	thorium
	Plutonic origin	1.9×10^{-12}	radium		
Sedimentary Rocks-					
clay		1.5×10^{-12}	radium	1.3×10^{-5}	thorium
	Sandstone	1.4×10^{-12}		$.5 \times 10^{-5}$	thorium
Limestone and dolomite		$.9 \times 10^{-12}$		$.1 \times 10^{-5}$	thorium

According to Goldschmidt the amount of radioactive material in minerals may be determined with sufficient accuracy by spreading pulverized samples upon one electrode in an ionization chamber.

Ambronn has measured the radioactivity of an oil well (results published by Heiland), which showed a slight solubility of emanation in the oil with little in the salt water. There is a very high radioactivity directly below the oil layers, the explanation of which is still unknown. The lead mines in Sergeslande show considerably greater rays where the lead veins protrude. Ambronn gives clear evidence of increases in radioactivity of 600 to 2,000 per cent to that in adjacent territory encountered in going over a change of strata.

The helium wells in the United States show only weak radioactivity. Sieveking and Lautenschlager question the connection between helium and radioactivity in springs and gas wells. Joly has evidence from the St. Gothard Tunnel that local heat sources are associated with radioactive rocks. Consult the United States Geological Survey for any questions of geologic structure. There is some evidence that these methods may be used for delineating faults.

Digitized by Google

Following is a short bibliography. For more comprehensive reference see Ambronn in Methoden der angewandten Geophysik.

BIBLIOGRAPHY

General Texts upon Radioactivity.

Curie P., Traite de radioactivite, Vol. 1 and 2.
Rutherford, Radioactivity.
Meyer and von Schweidler, Radioactivitat.
Muller-Pouillets, Lehrbuch der Physik and Meteorologie, Vol. 4.
Hevesy and Paneth, Lehrbuch der Radioactivitat.
Makower, Mesures practiques en radioactivite.

Measuring Instruments and Methods.

Greinacher, Naturwissenschaftliche Wochenschrift, 1910, page 659, (Photometric).
Levin and Ruer, Physikal. Ztschr. Vol. 9, 1908 (Photometric).
Ebler, E. Ztschr. angew Chem., 1909 (Photometric).
Lucas, R., Radioaktive Stoffe, Gmelin--Kraut--Friedhein--Peters, Vol. 3, (Fluoroscopic methods).
Kaye, G. W. C., "X-Rays" (General, Electrometer).
Bergwitz, K., Physikal. Ztschr., Vol.11, 1910 (Galvanometer methods).
Elster and Geitel, Physikal. Ztschr., Vol. 4, 1903 (Improved Electroscope).
Lichtenecker, K., Physikal. Ztschr., Vol. 13, 1912 (Determination of Capacity of leaf Electroscopes).
Kohlrausch, Lehrbuch Prakt. Physik (Electrometer, general).
Dolezalek Electrometer, Stschr. Instr., Dec., 1901.
Hoffmann, G., Physikal. Ztschr., Vol. 13, 1912 (Electrometer).
Rumelin, G., Physikal. Ztschr., Vol. 13, 1912 (Quadrant electrometer).
Townsend, Phil. Mag., 1903 (Zero method, electrometer).
Maxwell, J. Clerk, Electricity and magnetism (Quadrant electrometer theory).
Orlich, E., Ztschr. Instr., 1908 (Quadrant electrometer theory).
Beattie, R., Electrician, 1910, 1912 (Quadrant electrometer theory).
Paterson, C. C., Rayner, E. H., and Kinnes, A., Inst. Else, Eng., 1913 (Quadrant electrometer theory).
Walker, G. W., Phys. Soc. Proc., 1904 (Quadrant electrometer).
Compton, A. H. and K. T., Phys. Rev., 1919 (Electrometer).
Lindemann, F. A. and A. F., and Keeley, T. C., Phil. Mag., 1924 (New form of electrometer).
Wulf, T. H., Physikal. Ztschr. Vol. 8, 1907; Vol. 10, 1909 (Wulf electrometer).
Bronson, H. L., Am. Jour. Science, 19, 1905 (Constant deflection methods).
Bronson, H. L., Phil. Mag., 1906 (Constant deflection method).
Hauser, Fr., Physikal. Ztschr., Vol. 13, 1912 (Discussion of errors).
Engler and Sieveking, Arch. de Geneve, 1905 (Fontaktoscope).
Engler, C., Ztschr. Elektrchem., Vol. 11, 1905. (Fontaktoscope).
Meyer, St., and Mache, H., Ver. phys. Geo. Vol. 11, 1909 (Improved fontaktoscope).
Schmidt, H. W., Ver. phys. Geo., Vol. 7, 1905; Physikal. Ztschr., Vol. 6, 1905 (Measurement of emanations in liquids).
Elster, J., and Geitel, H., Physikal. Ztschr., Vol. 4, 1903 (Portable apparatus).

Digitized by Google

Duane, W., C. X., 1909 (Calorimetric methods).
Elster, J., and Geitel, H., Physikal. Ztschr., Vol. 8, 1907 (Apparatus for measuring penetration of X-rays).
Bergwitz, K., Habilitationsschrift, Braunschweig, 1910 (Comprehensive Summary of X-ray measurement).
Kolhorster, Ztschr. Physik., Vol. 5, 1921 (X-ray apparatus).
Kolhorster, Monograph (Problems der kosmischen Physik) (X-ray measurement).
Hoffmann, Physikal. Ztschr., Vol. 26, 1925 (Variations of the X-rays).
Hess and Kofler, Physikal. Ztschr., Vol. 18, 1917 (Variation of the X-rays).
Ferdinand Braun, Jahrb. Radioactivitat u. Elektrotech (X-ray measurements).
Himstedt, F., Physikal. Ztschr., 1904 (Solubility of emanation in petroleum oils).
Fuji, K., Proc. Tokyo Mathematico--Phys. Society (Solubility of emanation in petroleum oils).
Burton, E. F., London--Edinburgh--Dublin, as above, 1904 (Solubility of emanation in petroleum oils).

Application of Radioactivity to Geophysical Prospecting.

Borne, G. D., Habilitationsschrift, Breslau, 1905 (Emanation in air extracted from ground).
Gerdien, H., Physikal. Ztschr., Vol. 6, 1905 (Measurement of ionization of the air).
Gockel, A., Die Radioaktivitat von Boden und Quellen, Sammlung Vieweg, Vol. 5. Kolhorster (See above).
Eve and McIntosh, Proc. and Trans. Royal Soc. Canada, Montreal, Ottawa (Drill hole in Beachville, Ontario).
Tscherepenkoff, J., Bull. Inst. Pract., 1925, vol. 14 (Radioactivity of Natural gas in Baku region). Geophysics, U.S.S.R.)
Winnacker, Ztschr. intern. Ver. Bohring. u. Bohrtechniker, Wien.
Goldschmidt, V. M., Ztschr. Kristall., 1908 (Measurement of radioactivity of minerals).
Lautenschlager, L., Physikal. Ztschr., vol. 13, 1912 (Sources of helium in natural gas).
Joly, J., Radioact. and Geol., London, 1909 (Radioactivity in St. Gothard Tunnel).

Digitized by Google